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Contractor Report ARPAD-CR-89001

EXPERT SYSTEM FOR TEST PROGRAM SET FAULT CANDIDATE SELECTION

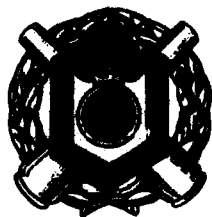
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R. Glenn Wright
Mary Blanchard
Prospective Computer Analysts, Inc.
1215 Jefferson Davis Highway
Suite 309
Arlington, VA 22202

P. Lyon
P. Janusz
Project Engineers
AMCCOM

September 1989

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION AVAILABILITY OF REPORT	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE		Approved for public release; distribution is unlimited.	
4. PERFORMING ORGANIZATION REPORT NUMBER		5. MONITORING ORGANIZATION REPORT NUMBER Contractor Report ARPAD-CR-89001	
6a. NAME OF PERFORMING ORGANIZATION Prospective Computer Analysts, Inc.	6b. OFFICE SYMBOL	7a. NAME OF MONITORING ORGANIZATION AMCCOM, PAD	
6c. ADDRESS (CITY, STATE, AND ZIP CODE) 1215 Jefferson Davis Highway, Suite 309 Arlington, VA 22202		7b. ADDRESS (CITY, STATE, AND ZIP CODE) Technology Office [AMSMC QAH-A(D)] Picatinny Arsenal, NJ 07806-5000	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION ARDEC, IMD STINFO Br	8b. OFFICE SYMBOL SMCAR-IMI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAA21-86-C-0225	
8c. ADDRESS (CITY, STATE, AND ZIP CODE) Picatinny Arsenal, NJ 07806-5000		10. SOURCE OF FUNDING NUMBERS	
		PROGRAM ELEMENT NO.	PROJECT NO. TASK NO. WORK UNIT ACCESSION NO.
11. TITLE (INCLUDE SECURITY CLASSIFICATION) EXPERT SYSTEM FOR TEST PROGRAM SET FAULT CANDIDATE SELECTION			
12. PERSONAL AUTHOR(S) R. Glenn Wright and Mary Blanchard, Prospective Computer Analysts, Inc. P. Lyon and P. Janusz, Project Engineers., AMCCOM			
13a. TYPE OF REPORT Final	13b. TIME COVERED FROM Sep 86 to Mar 87	14. DATE OF REPORT (YEAR, MONTH, DAY) September 1989	15. PAGE COUNT 28
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)	
FIELD	GROUP	SUB-GROUP	Expert system, Artificial intelligence, Automatic test equipment (ATE), Test program set (TPS), Automatic test program generation (ATPG), Fault inspection, Verification and validation, TPS acceptance tool.
19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)			
This report describes an application of expert system technology to test program set (TPS) verification and validation. The goals of this project are to reduce the complexity and time requirements for testing test program software, and at the same time reduce the level of expertise required by acceptance test personnel. This work effort was funded by the U.S. Army Armament Research, Development and Engineering Center (ARDEC) in Dover, NJ.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL I. HAZENDARI		22b. TELEPHONE (INCLUDE AREA CODE) (201) 724-3316	22c. OFFICE SYMBOL SMCAR-IMI-I

DD FORM 1473, 84 MAR

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Editors Note

EQUATE is the ATE convention that has been used by the U.S. Army for many years now. A decision was made by the U.S. Army to replace EQUATE with IFTE. Since all new TPS development will be performed using the IFTE ATE, the vast majority of all TPS acceptance in the future will be IFTE test programs, not EQUATE. This expert system would be of greatest benefit to ARDEC if it addressed IFTE, rather than EQUATE. In short, IFTE is the U.S. Army's ATE for the future, and EQUATE will be retired eventually.

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INTRODUCTION

As units under test (UUT) testable with automatic test equipment (ATE) increase in both number and complexity, and the technically experienced personnel required to perform independent verification and validation (IV&V) of UUT test programs continue to be in short supply, alternative means of performing test program IV&V must be developed in order to reduce the significant investment in time and resources currently devoted to this effort. The primary requirement of the alternative, however, must be to ensure the suitability and correctness of the test program for detecting and correctly diagnosing UUT failures.

The Expert System for TPS Fault Candidate Selection is one means to achieve this objective. To assist in performing test program IV&V, the expert system analyzes characteristics of the test program (TP) and UUT circuit architecture, performs several quality assurance functions relating to TP and UUT consistency, then selects faults for insertion in the UUT based on test program structure, circuit characteristics and the application of rules utilized by human experts in accomplishing this task.

The expert system was developed and successfully demonstrated as a prototype to ARDEC in March 1987. All functions required in the production expert system were fully incorporated into the prototype, and three existing test programs in ARDEC's inventory were used to validate the results in testing the expert system. In subsequent paragraphs, general principles of fault selection criteria for TPS IV&V will be addressed, along with the hypotheses for their implementation in an expert system environment. Benchmark test results will be analyzed for overall performance and compared to results obtained from human experts.

Human Approach to Test Program Independent Verification and Validation

Independent Verification and Validation for test programs is typically performed in stages by QA Engineers. The first stage encompasses review of UUT source data to gain an understanding of the function and operation of the UUT. This is followed by review of the test program to evaluate the testing performed therein. Much of this effort entails routine comparison of the test program content to UUT content to determine:

1. if all detectable component failure modes are called out in the program,
2. whether ambiguity group sizes and fault isolation capability meet contractual requirements, and
3. other bookkeeping tasks that need to be performed.

Once the engineer is satisfied the program addresses the basic characteristics of the UUT and the contract. The test philosophy and logic flow are analyzed to ensure the test program actually performs the testing that is apparent on the surface. With this done, the engineer selects fault modes of components for inclusion in a fault list, to then be demonstrated as detectable and correctly diagnosed by the test program. Fault selection and fault list development is highly subjective. It is based primarily on the previous experience of the engineer with the same type of circuits, as well as engineering analysis of the test program to ensure that adequate GO/NOGO chain testing is performed.

Expert System Background

The development of this expert system is being accomplished in three phases. During Phase I, which has been completed, a prototype expert system (containing the basic constructs required for a production system) was successfully demonstrated in order to show proof of concept. In Phase II, a production expert system will be completed which addresses all ARDEC UUT testing requirements. In Phase III, the expert system will be expanded to address the requirements of test programs for US Navy and Air Force applications.

PHASE I

In the initial development phase, the expert system was modeled and implemented as a prototype capable of executing all functions of the production expert system, but on a smaller scale to demonstrate the feasibility of the approach. A large prototype, the expert system consists of 4 frames, 131 rules, 3 meta-rules, 279 parameters, and 175 functions. The development and execution environment was a Texas Instruments Business Pro utilizing the TI Personal Consultant Plus expert system shell.

Briefly defining the terms used here in describing the prototype expert system, the following applies:

1. FRAME - Frames are used to break the domain's knowledge into smaller chunks of knowledge or break the problem into sub-problems. Data structures such as rules and parameters are used to represent knowledge. This definition only applies to Personal Consultant Plus.

2. **RULE** - Rules are used to represent the expert's reasoning methodologies. Rules allow the system to make inferences based upon known facts. These facts are represented as parameters. Additionally, functions can be called from rules. An example is:

If Resistor = Carbon
Then Valid_Failmode = Open

3. **PARAMETER** - Parameters are used to represent facts in the domain. The parameters can be assigned values within a rule, within a function, or by the user.

4. **META-RULE** - These allow the system to reason about the rules, containing the expert's reasoning methodologies. For instance (in English):

If this UUT was previously entered
Then do not ask user for list of non-detectable faults

5. **FUNCTIONS** - Functions are subprograms written in PC-Scheme, Texas Instrument's version of LISP for a PC.

Four frames, called FAULT-SELECT, UUT, CIRCUIT-APP and TEST-PROG perform individual functions which relate to the unique areas addressed by the expert system. FAULT-SELECT is the root frame and contains 45 rules, 3 meta-rules, 142 parameters and 175 functions. The purpose of FAULT-SELECT is to control the processing of the expert system and to select the fault list for insertion into the UUT during test demonstration. UUT is the child frame of FAULT-SELECT and contains 22 rules and 30 parameters, and its purpose is to acquire data regarding UUT architecture. CIRCUIT-APP is also a child frame of FAULT-SELECT and contains 40 rules and 77 parameters. The purpose of CIRCUIT-APP is to determine those faults which are non-detectable and eliminate those from the fault list of possible faults. TEST-PROG is the child frame of CIRCUIT-APP and contains

25 rules and 30 parameters. Its purpose is to acquire data and make conclusions regarding test program characteristics. The relationships and communications between frames are illustrated in Figure 1.

Scope of Prototype Expert System

The prototype expert system was designed to analyze test programs and analog shop replaceable units (SRU) containing the following components:

1. Resistors (Carbon, Wirewound, Flatpack)
2. Capacitors (Ceramic, Electrolytic)
3. Inductors
4. Relays
5. Diodes
6. Transistors
7. Integrated Circuits

For all resistors, capacitors, inductors, and relays, failure mode and default failure rate information is represented as a parameter value.

Electronic Component Libraries

Diode, transistor and integrated circuit data is contained in libraries accessed by frame UUT. All library entries are listed by commercial/Mil part number. Diodes and transistors are also represented in addition by default failure rate values (calculated based on MIL-HBK-217 techniques) and diode or transistor type used to assist in determining the appropriate fault mode to be included in the fault list for insertion during demonstration. Integrated circuit descriptions contain, in addition to part

number and default failure rates, individual pin-by-pin functional descriptions consisting of logic family, failure mode, function, and other information relevant to a particular IC.

Domain Expert Interviews

Experts in TPS development and analysis (the domain) were interviewed and general rules were formulated based upon the methods and procedures used in analyzing sample test cases they reviewed. These rules were incorporated into the several frames as appropriate for the type of knowledge involved. For example, rules regarding test program analysis were incorporated into frame TEST-PROG, UUT analysis into frame UUT, and circuit analysis into frame CIRCUIT-APP.

Data Acquisition

Data acquisition by the prototype expert system was performed interactively with the user. Because the intent of Phase I was to show concept feasibility, the majority of efforts were undertaken to achieve this, rather than to promote user friendliness and utility. Future development will focus on improving the user friendliness of the tool, as well as expanding its capability.

Testing

The ability of the expert system to analyze UUT and test program information and apply expert knowledge to derive conclusions leading to a fault list for insertion during test program demonstration was tested

utilizing three analog SRU test programs supplied by ARDEC. The tests were structured so that three human experts would review the test programs and UUT source data and generate fault insertion lists. The expert system would do the same task independent of human experts. The goal of a successful test would be that the majority of human experts would agree that the expert system obtained valid results in selecting components and failure modes for insertion at demonstration. It was not anticipated that the expert system would match the results of any one human expert, just as it is not anticipated that human experts will agree with each other in circumstances where subjective thought is required.

The results of testing indicated that the expert system selected faults that were distributed across all functional areas of the UUT and tested program paths throughout the test program. Of fault candidates selected by the expert system, several were contained within the same ambiguity groups selected by a human expert.

Phase I Summary

Summarizing the results of the prototype expert system development effort, the performance of the expert system was comparable to that of a human expert within the limited development domain. Faults selected by the expert system were distributed throughout the test programs and across UUT functional areas, and the expert system followed the same general strategy utilized by humans in performing this task. All goals set for its performance were met or exceeded. The prototype would not be satisfactory for general use as greater hardware and software capability, automated data acquisition and a high degree of user friendliness and graphics capability would be required. These features will be incorporated into the phase II expert system.

PHASE II

Following the development of the prototype expert system, the full scale production expert system will fully address, analyze and test analog shop replaceable unit (SRU) test programs, and contain provisions for testing SRU test programs generated with the aid of Automatic Test Program Generation (ATPG).

Expert System Enhancements

The phase II expert system will possess significantly greater capability than the prototype expert system developed in phase I. The greatest enhancements involve the automation of test program and UUT data collection activities. Additional capabilities include the representation of 17 variations of 13 basic electronic component types, of which the following have been added:

1. Variable Resistor
2. Switch
3. Delay Line Transformer
4. Motor
5. Fuse
6. Circuit Breaker

The phase II expert system will vastly expand the procedures used for test program and UUT analysis. All electronic components will be fully modeled, and component libraries will be expanded to include hundreds of additional part number references. One additional library is included for

relays. Additional functions to improve the utility of the expert system will also be added.

The production expert system will reside on a SUN 360 and will be implemented in C language with the aid of the expert system shell NEXPERT and the ORACLE database management system. Expert knowledge will be implemented in the form of rules and schemas. Pattern matching will be used to invoke rules, and viewpoints will be implemented. Graphics capability will be widely implemented to improve user interfaces. Figure 2 illustrates the Phase II expert system.

Test Program Independent Verification and Validation

Test program IV&V will be conducted in two stages. In the first stage, quality assurance functions are performed in the test program prior to selecting faults for inclusion in a fault list. In the second stage, data regarding UUT architecture and test program content are obtained by the expert system through automated means and interactive user interface.

Routine Data Analysis

Routine data checks are conducted in two main areas: test program continuity and test program/UUT discrepancies. The test program is initially checked to determine that logic continuity exists throughout the program. Following this, the data content of the test program and the UUT knowledge base is compared for discrepancies. This will determine whether the test program contains all non-detectable component reference designations within ambiguity groups, and whether component reference designations exist that are not present on the UUT.

Optional Analyses

Additional analysis of test program features may be performed on an optional basis. Contract compliance may be checked with regard to ambiguity group size percentages as compared to the overall program. Measurement parameters for this feature may be adjusted to match individual contract requirements. Typical results obtained by performing this optional check are illustrated in Table 1.

Another analysis of the test program will determine whether components contained in ambiguity groups are ordered by failure rate. This is accomplished by referencing known failure rate data, or default failure rate information (contained within the knowledge base and electronic component libraries).

A relative measure of test program efficiency may be obtained based on the analysis of high failure rate component failure mode locations in the test program. When high failure rate modes are detected early in the test program, a higher test program efficiency rating will be given than if high rate of failure component detection is delayed until the later portions of the program.

An option to print the diagnostic flow chart representative of test program data contained within the knowledge base will also be provided.

Routine analysis will be performed immediately before the initiation of the expert system. Optional analyses are not anticipated to be performed until the test program successfully completes all routine analyses.

Expert System Utilities

Utilities will be incorporated into the expert system to accomplish test program and UUT data acquisition both automatically and through user interaction. The ATLAS language test program will be parsed to obtain logic flow and ambiguity group data. This will be accomplished automatically. Data obtained provides explicit information regarding the test program, and implicit information regarding UUT architecture as related to component makeup and functional configuration. Additional UUT data will be obtained from the user through specifically directed questions and graphics-enhanced interactive processing.

Description of Expert System

From a list of approximately 100 faults, the expert system will select the best faults to implement, based on the results of test program and UUT analysis and the application of expert knowledge. Information associated with each fault will be grouped together as a single entity for each fault. The data structure used to represent this single entity is referred to as a schema.

Schemas are used to describe objects or events. An object has associated characteristics and these are represented as slots of the schema. The actions typically associated with an event would be represented in the slots of a schema describing an event. Schemas can also be grouped together to describe more complex objects or events.

The expert's reasoning strategies will be incorporated into forward and backward chaining rules. A forward chaining rule starts with some initial data and works forward to make conclusions based upon the data. A backward chaining rule begins by assuming a conclusion/hypothesis is

true and tries to prove the conditions necessary for this hypothesis. These two strategies will be combined to try to emulate the expert's reasoning process as closely as possible.

The forward chaining and backward chaining processes may be interrupted by a message from the user, another process or function, in order to process a goal. These goals will have a priority level associated with them. Additionally, during the problem solving process alternate goals can be generated dynamically. For example, when the current strategy appears to fail, an alternate strategy can be pursued. Acceptance test personnel can also employ what-if hypothetical reasoning to explore changes in fault selection when the emphasis is shifted from failure rate to specific UUT functional areas, or to particular test program paths.

The expert system is based upon non-monotonic reasoning, which will cause the system to reevaluate past inferences when new information is available. New information may include resetting or changing a hypothesis or a subgoal, caused by exploring hypothetical situations. Or a goal may be reset during an iteration process. It is also possible that this new information will cause a contradiction in the knowledge base. The system will detect this contradiction and, according to the setting of a switch, either change its current hypothesis or ignore the new information. This last step is similar to the way humans alter their knowledge when new information becomes available. Where operations which cannot be performed within the context of the expert system development tool are required, special functions written directly in C will be developed.

In order for the engineer to understand the reasoning process behind the system's fault selection, two operations are provided. One provides the user with the reasoning behind the current strategy. The other gives the complete line of reasoning used in extracting the reasoning processes used by experts, including asking the engineer to select the faults with a time constraint or providing the engineer with incomplete data to make his/her selection. The knowledge acquisition process will continue throughout the

development of the expert system. To ensure the validity of the expert system's reasoning process, the engineers will periodically be provided with the faults selected by the expert system and the reasoning used in making these selections.

PHASE III

A third phase of development is anticipated following completion of the full scale production expert system for ARDEC. Further enhancements will be implemented with regards to digital SRU and LRU test program analysis capability, and in addition to research in more sophisticated means of knowledge acquisition for expert rules. In addition, direct UUT data acquisition through optical schematic scanning and other techniques will be investigated. Presently, more than 7 potential users in the Army, Navy and Air Force have expressed interest in Phase III participation. Many of the innovations being developed in this project have applications in the commercial realm as well, particularly in the area of automated knowledge acquisition and pattern recognition.

SUMMARY

The concept of utilizing an expert system for evaluation of test programs has been successfully demonstrated for analog shop replaceable units. The full scale development of a UNIX based expert system utilizing automated test program and Unit Under Test (UUT) data collection, will result in a practical, user friendly tool capable of augmenting a QA/TPS acceptance engineer during independent verification and validation. The expert system will provide the QA engineer with previously unavailable

information, results of analyses and access to human expert knowledge regarding test program and UUT testing, resulting in greater human efficiency in performing this task.

Table 1. Ambiguity Group Size Percentages

AMBIGUITY GROUP SIZE	PERCENTAGE
5 or less	90%
6 to 8	6%
9 to 11	0%
12 or more	4%

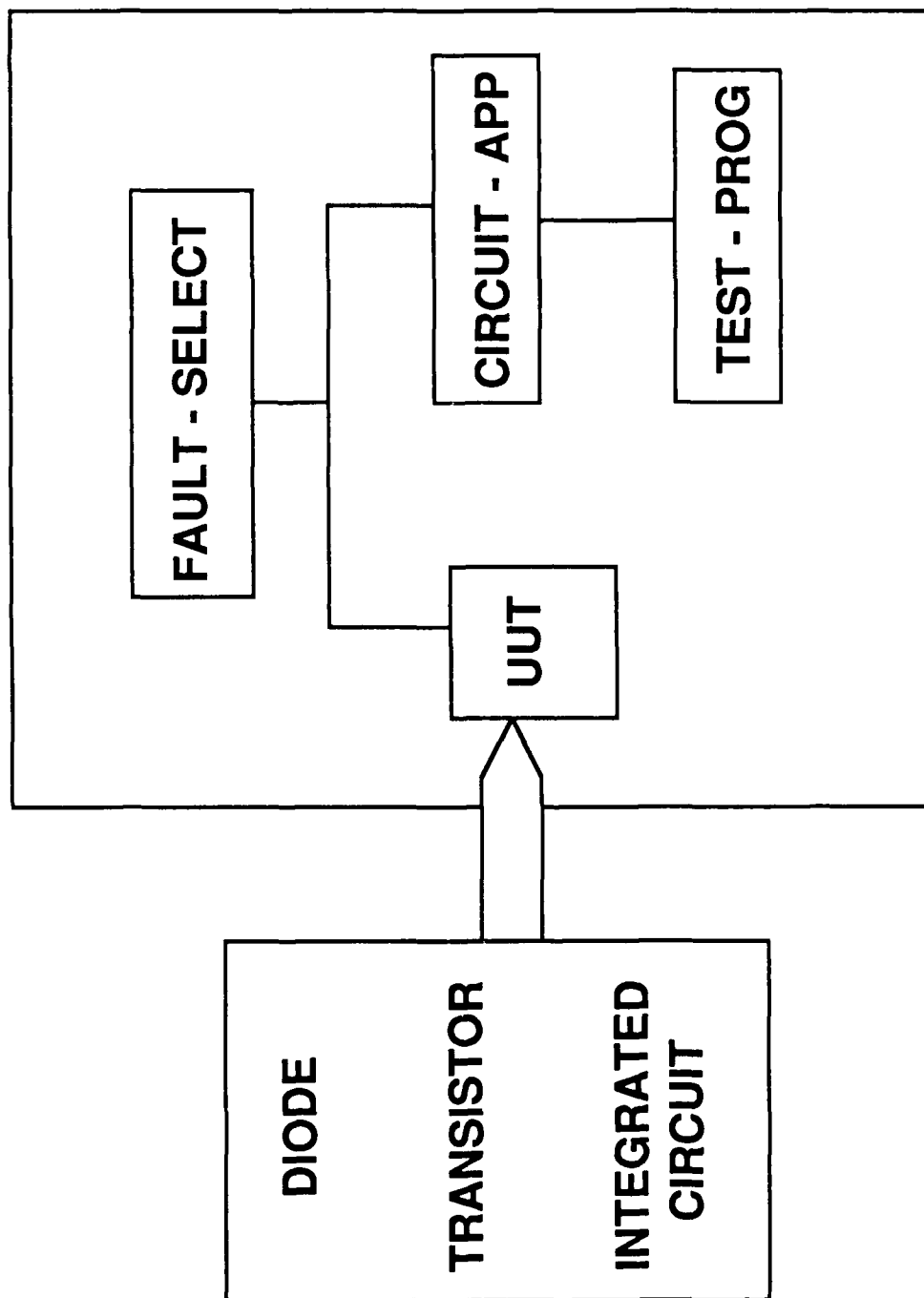


Figure 1 - PROTOTYPE EXPERT SYSTEM

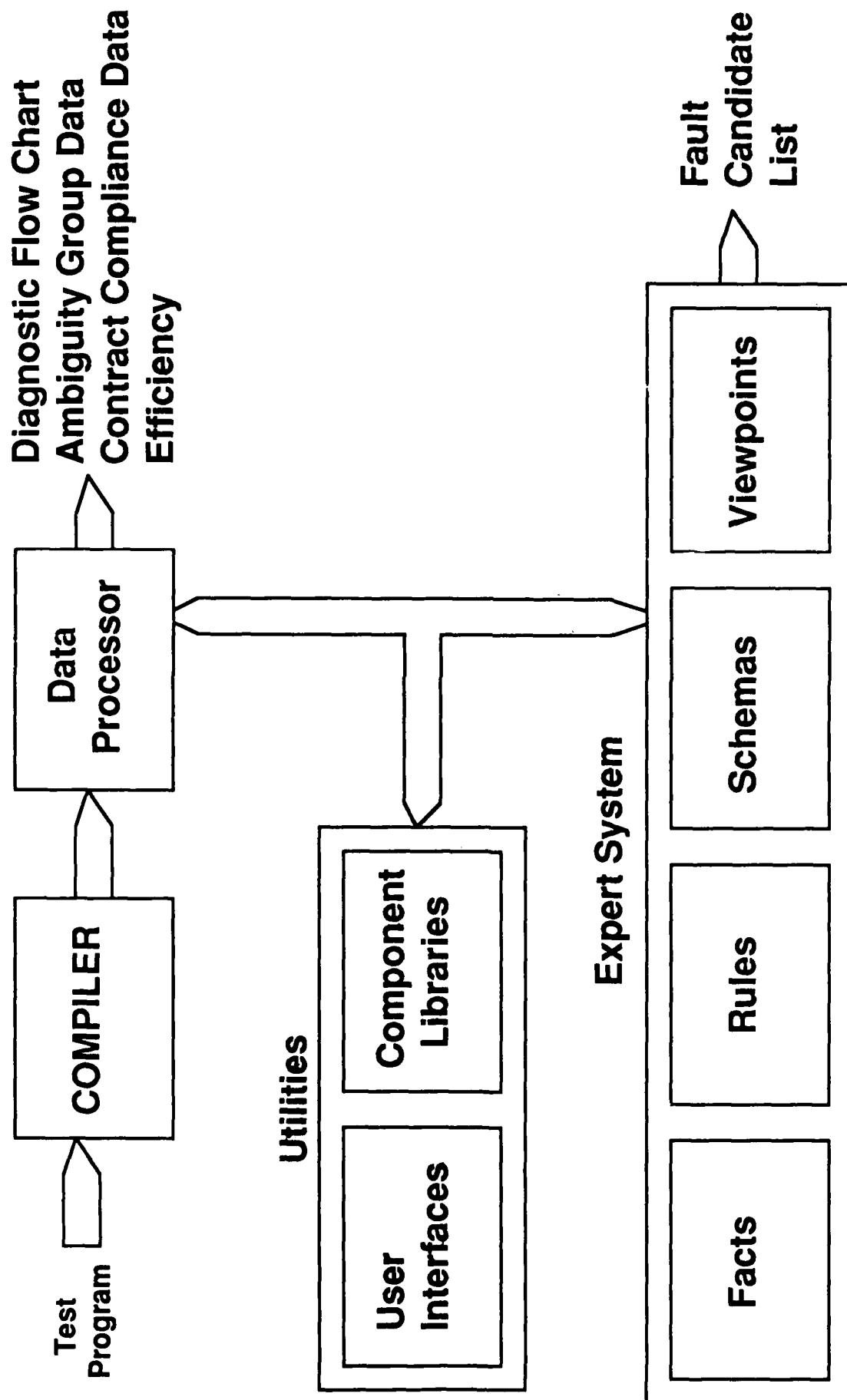


Figure 2 - Expert System for TPS Verification/Validation

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List of Acronyms

TPS	Test Program Set
UUT	Unit Under Test
ATE	Automatic Test Equipment
IV&V	Independent Verification & Validation
SRU	Shop Replaceable Units
LRU	Line Replaceable Units
IC	Integrated Circuit
ATPG	Automatic Test Program Generation
QA	Quality Assurance
IFTE	Intermediate Forward Test Equipment

APPENDIX

Relationship of Test Hardware/Software Components

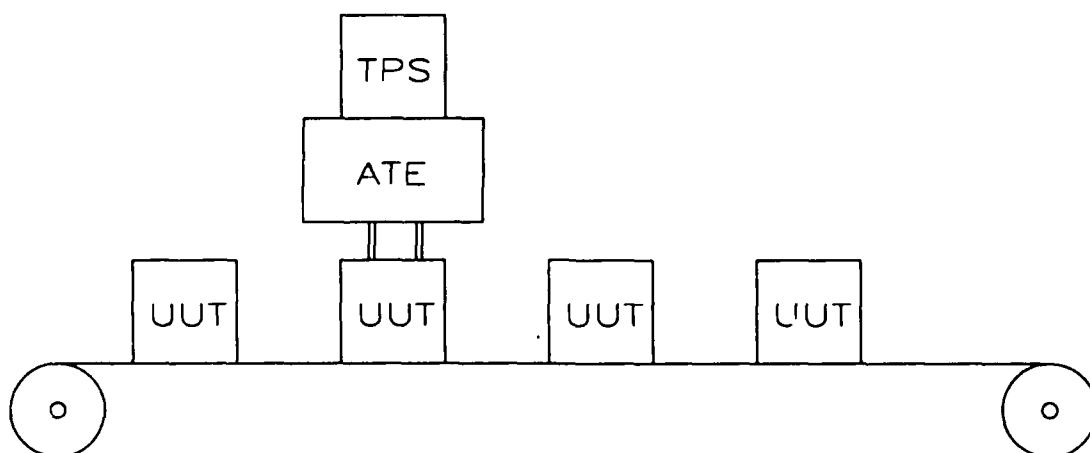


Figure 1

Functional Relationship of Expert System

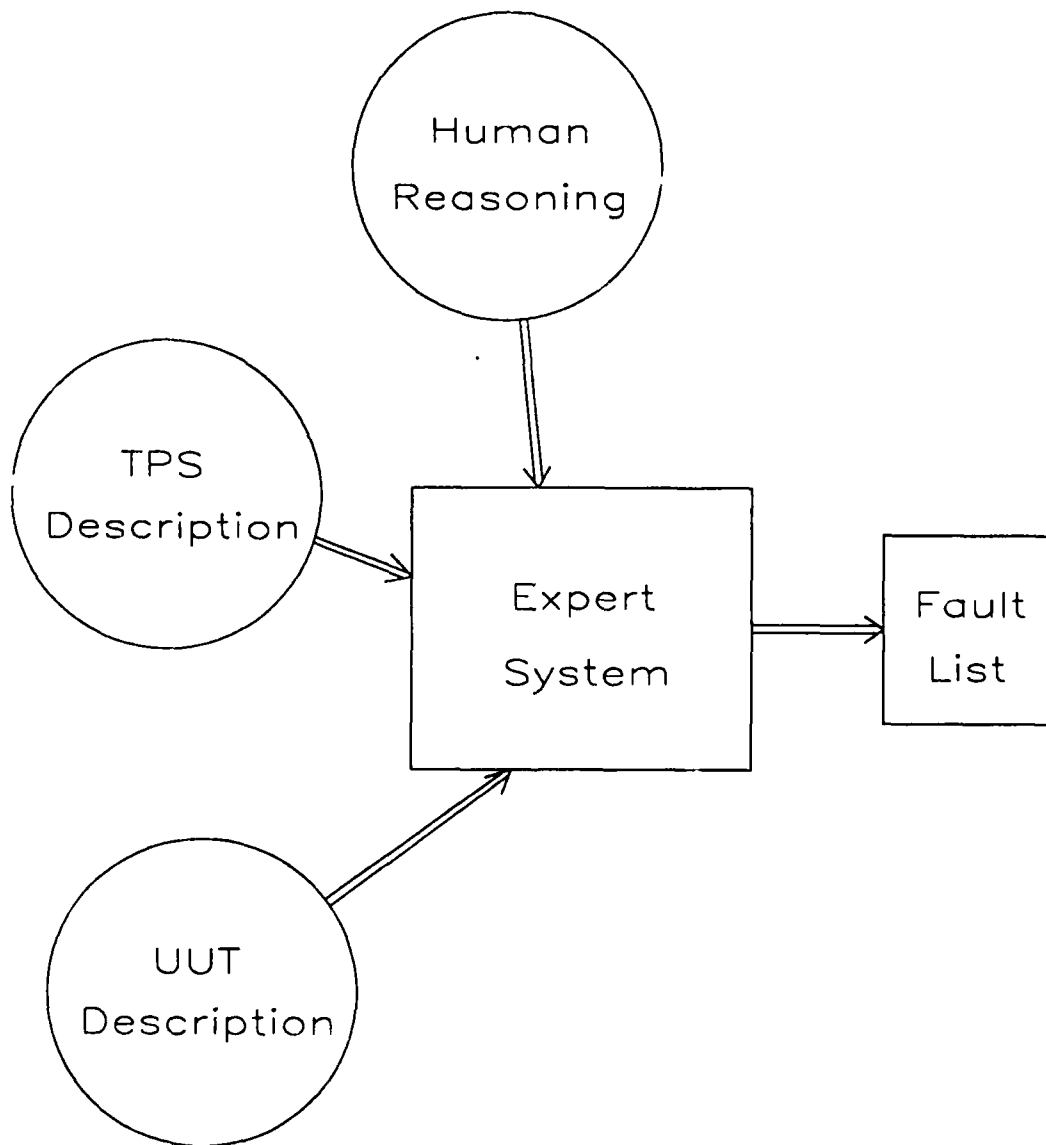


Figure 2

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SMCWV-PPI, W. Garber
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AMCQA-P, E. Lesser
5001 Eisenhower Ave.
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AMSLC-EN-PA, Mr. John Goon
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R. G. Shelton
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U.S. Army AMCCOM
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W. Maurits
Aberdeen Proving Ground, MD 21010-5423

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F. Braun
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AMSTA-RCKM, Mr. D. Ostberg
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U.S. Army Troop Support and Aviation
Material Readiness Command
ATTN: AMSTS-Q, W. G. Creel
4300 Goodfellow Boulevard
St. Louis, MO 63120-5720

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U.S. Army TROSCOM
ATTN: AMSTS-Q
St. Louis, MO 63120

Commander
U.S. Army TROSCOM-BRDEC
ATTN: STRBE-TQ, Mr. Lawrence Makowsky
Ft. Belvoir, VA 22060-5606

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U.S. Army TECOM-WSMR
ATTN: STEWS-TE-OE, Ms. Marthe Wygant
White Sands, NM 88002-5070

Commander
U.S. Army ALMC
ATTN: AMXMC-ACM
Ft. Lee, VA 23801

Commander
U.S. Army DLA
ATTN: DLA-QES, Mr. Armond Darrin
Cameron Station
Alexandria, VA 22304-6100

Commander
U.S. Army DCASR
ATTN: DCASR-PHI-QTX, Ms. Ann Quinn
2800 So. 20th St.
Philadelphia, PA 19101

Commander
U.S. Army DCASR-NY
ATTN: DCASR-QT, Mr. Mike Spezzaferro
201 Varick St.
New York, NY 10014

Commander
U.S. Army SE&L
ATTN: AMXMC-SEL-E, Dr. David Jenkins
Texarkana, TX 75507-5000

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U.S. AMETA
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Chief ACSD
ATTN: ATZH-CDC
Ft. Gordon, GA 30905

Director
Materials Technology Laboratory
ATTN: SLCMT-D
SLCMT-DD
SLCMT-MS
SLCMT-OM
SLCMT-MC
SLCMT-TP
SLCMT-MSI
SLCMT-MSI-NE
SLCMT-OMP
SLCMT-MCM-SB
Watertown, MA 02172-0001

Commander
U.S. Army Dugway Proving Ground
ATTN: STEDP-MT-AT, K. Dumbauld
STEDP-MT-C-T, F. Bagley
STEDP-PO, J. McKenzie
Dugway, UT 84002-5000

Commander
Harry Diamond Laboratories
ATTN: SLCHD-PO-P, J. Hoke
2800 Powder Mill Road
Adelphi, MD 20783-1197

Commander
U.S. Army Electronic Technology and Devices Laboratory
ATTN: SLCET-R, J. Key
Ft. Monmouth, NJ 07703-5302

Commander
U.S. Army Yuma Proving Ground
ATTN: STEYP-MTD, W. E. Brooks
Yuma, AZ 85365

Commander
U.S. Army White Sands Missile Range
ATTN: STEWS-QA, C. Treat
White Sands Missile Range, NM 88002

Commander
U.S. Army Tropic Test Center
ATTN: STETC-LD-M
APO Miami, FL 34004

Commander
Anniston Army Depot
ATTN: SDSAN-DQA, Mr. Pennington
Anniston, AL 36201

Commander
U.S. Army Depot System Command
ATTN: AMSDS-QM, B. Newman
 AMSDS-Q-E-T, Douglas Hanna
Chambersburg, PA 17201-4170

Commander
U.S. Army Pine Bluff Arsenal
ATTN: AMCPB-QA, H. Love
Pine Bluff Arsenal, AR 71611

Commander
Corpus Christi Army Depot
ATTN: SDSCC-Q, D. L. Ross
Corpus Christi, TX 78519

Commander
U.S. Army Jefferson Proving Ground
ATTN: STEJP-TD, MAJ A. Alquin
Madison, IN 47250

Commander
Letterkenny Army Depot
ATTN: ADSLE-Q, G. Mantooth
Chambersburg, PA 17201-4150

Commander
U.S. Army New Cumberland Army Depot
ATTN: SDSNC-Q, A. T. Holderbach
New Cumberland, PA 17070

Commander
Red River Army Depot
ATTN: SDSRR-Q, W. D. Wuertz
Texarkana, TX 75501

Commander
U.S. Army Electronic Proving Ground
ATTN: STEEP-MT, LTC J. R. Sutherland, Jr.
Ft. Huachuca, AZ 85613

Commander
Lexington Blue Grass Army Depot
ATTN: SDSLB-QA, J. Palmer, Jr.
Lexington, KY 40511-5100

Commander
Sacramento Army Depot
ATTN: SDSSA-Q, R. Bragg
Sacramento, CA 95813-5027

Commander
Savanna Army Depot Activity
ATTN: SDSLE-VS
Savanna, IL 61074-9636

Commander
Seneca Army Depot
ATTN: SDSSE-R, P. W. Chavez
Romulus, NY 14541

Commander
Sharpe Army Depot
ATTN: SDSSH-Q, J. E. Seyfried
Lathrop, CA 95331

Commander
Sierra Army Depot
ATTN: SDSSI-QA, V. Steed
Herlong, CA 96113

Commander
Toole Army Depot
ATTN: SDSTE-QA, R. M. Rich
Toole, UT 84074-5010

Commander
Pueblo Depot Activity
ATTN: SDSTE-PUQ, J. Farley
Pueblo, CO 81001

Commander
Tobyhanna Army Depot
ATTN: SDSTO-Q, W. J. Lord
Tobyhanna, PA 18466

Sandia National Laboratories
ATTN: SQAE, Mr. Darl Patrick
Quality Assurance Div. 2854
Albuquerque, NM 87185

Commander
U.S. Army AMCCOM
ATTN: AMSMC-QAV-A, Mr. Bill Thetford
Edgewood, MD 21010-5423

Commander
U.S. Army AVSCOM
ATTN: AMSAV-Q, Mr. Henry Fong
 AMSAV-QP, Mr. Mark Vail
St. Louis, MO 63120

Commander
U.S. Army CECOM
ATTN: AMSEL-PA-MT-S, Mr. Paul Kogut
 Mr. Andy Mills

 AMSEL-PA
 AMSEL-PA-DL
 AMSEL-RD-SE-CRM-CM
 AMSEL-RD-SE-AST
Ft. Monmouth, NJ 07703-5023

Director
U.S. TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002

Commander
USA OTEA
ATTN: CSTE-TS-S, R. Wilson
5600 Columbia Pike
Falls Church, VA 22041-5115

Commander
USA CSTA
ATTN: STECS-DA-CO, Mr. F. Moratta
Aberdeen Proving Grounds, MD 21005-5059

Commander
USAF Human Resources Lab
ATTN: AFHRL/LR, MAJ Loudermilk
Wright Patterson AFB, OH 45433-6503

Commander
U.S. Army AMCCOM
ATTN: SMCAR-FSF-A, Mr. Tom McIvor
Mr. Jerome Romania